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OBSERVATIONS UPON FLUTTER AND FIBRILLATION.

PART IX.—THE NATURE OF AURICULAR FIBRILLATION AS IT OCCURS IN PATIENTS.

By THOMAS LEWIS.

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OBSERVATIONS UPON FLUTTER AND FIBRILLATION.

PART IX.—THE NATURE OF AURICULAR FIBRILLATION AS IT OCCURS IN PATIENTS.

By THOMAS LEWIS.*

An observation upon impure flutter.

BEFORE proceeding to the main subject of the present article an observation is to be described which confirms a conclusion of a previous article. The term impure flutter has been used to designate varieties of flutter, disturbed in lesser or greater degree. It is the smooth course of the excitation wave which is disturbed, and the interference appears on occasion to be very local. This conclusion rests chiefly upon observations in which simple irregularities in the direct leads are compensated; the auricular complexes in limb leads presenting throughout no sign of disturbance. In support of the same conclusion, a record (Vol. VII, page 335, Fig. 10) has been published, showing that at one point of the auricular surface a series of excitation waves appeared regularly, while the simultaneous limb-lead indicated disturbed flow in some other region of the auricle. The conclusion that a disturbance in the smooth flow of the excitation wave in flutter may be purely a local event is one of consequence to the hypothesis which would explain fibrillation; the record now to be described supports this conclusion.

The record is shown in Fig. 5. It is one of the simplest of a series taken from the same animal,† all of which showed either impure flutter or fibrillation of the auricle. The curves were taken simultaneously from three sets of closely paired contacts, placed in line upon the body of the auricle and parallel with the sulcus terminalis. The arrangement of the contacts, each pair of which covered 8 millimetres of muscle, is shown to the right of Fig. 1, in which the deflections of the record are charted. The method of charting is similar to that which has been used previously.‡

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* Working on behalf of the Medical Research Council.

† All the dogs used for the observations of this article were fully anæsthetised with morphia, paraldehyde and ether throughout the experiments.

‡ As the amplitude of the deflections varies little, these are drawn of equal height in the diagram to simplify it.

Consider the last five charted deflections *j* to *n*. The events are regular. In each record is a series of deflections which, by their downward direction, all indicate that the excitation waves to which they correspond strike the *c* contacts first of all; the order of precedence in the three curves is harmonious with the direction of the deflections, each excitation wave strikes contacts *1*, *2* and *3* in that order. The waves are proceeding regularly from the inferior caval to the superior caval region. But at the two points the record is disturbed, namely, by waves *c* to *j*. In the centre curve (*i* in Fig. 5) an upright deflection appears, and it is slightly but definitely premature (0·1289 of a second); during the preceding cycle a different form of disturbance is seen in lead *3*, here the deflection is slightly but definitely delayed (0·1412 of a second) though its form does not alter. Both these disturbances *are precisely compensated*; compensation occurs at once in the case of the premature beat; in the case of the delayed beat, compensation is hindered because the excitation wave *i* is premature in lead *3* in sympathy with its prematurity in lead *2*. The precise compensation of the double disturbance is appreciated when the time relations of deflections *f* and *g* are compared with those of deflections *j* and *k*, and when it is noticed that in lead *1* the deflections are regular in their incidence over the disturbed period. Now the two disturbances, prematurity of one deflection and delay of the other, do not appear to be connected; for in an earlier part of the record, similar disturbances are seen (waves *a* and *c*), but here they are separated by deflections (*b*) having the usual time relations to each other.

The excitation waves which strike the first pair of contacts are waves emanating from the central circus movement at regular intervals. Usually the same excitation waves, or corresponding and parallel waves, flow regularly over the second and third pair of contacts, yielding a regular and repeated motion. But the waves *c* and *j* take a slightly quicker path to the second pair of contacts; these waves have deviated from their accustomed course; to the waves *a* and *h* there has been some slight obstruction in their passage to the third pair of contacts. The courses of the waves are indicated in a diagrammatic fashion in the figure. The irregularity of flow is a local affair; the contacts have been so placed that all have not been affected. The disturbance occurs in one case between the first and second pairs, in the other case between the second and third pairs.

Definition and preliminary discussion of auricular fibrillation.

In previous articles of this series the word fibrillation has been used in speaking of a form of disordered auricular action. Now the term "auricular fibrillation" does not as yet convey a precise or universal meaning; it has been defined, deliberately or by inference, in different ways by different workers. It has been defined upon the basis of visible or mechanically recorded events in the auricles, of its influence upon the ventricle, of the hieroglyphic of the electrocardiogram. The term has usually been extended

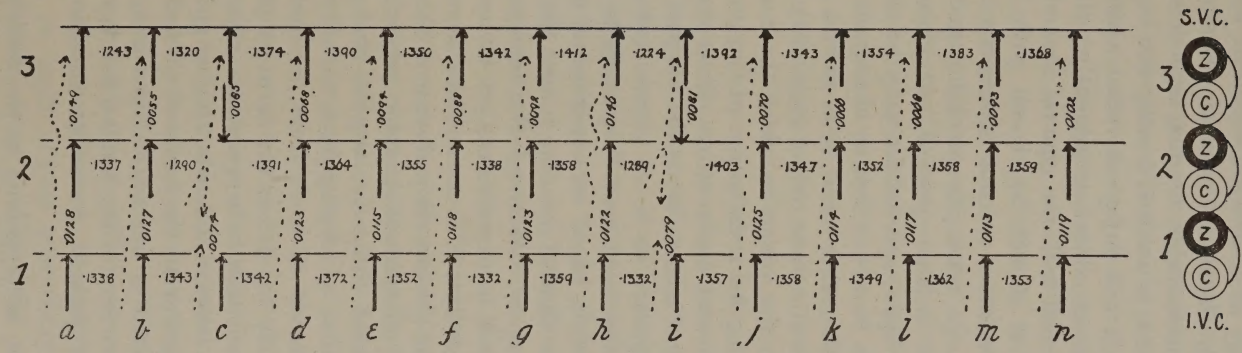

Fig. 1. *Dog LD.* (*Record* 8.) A portion of Fig. 5 is charted. A diagram of the contacts, as they were arranged on the tænia terminalis is shown to the right of the chart. The heavy arrows represent the time relations of the intrinsic deflections of the record to each other ; the arrows are drawn up or down to the corresponding base lines according as the deflections were upwardly or downwardly directed in the curve. The direction of the arrow indicates the direction in which the excitation wave passed the corresponding pair of contacts. The cycle lengths are written horizontally and the transmission intervals vertically in decimals of a second. The broken arrows represent the course of the excitation waves over the contacts as a whole.

to include the disturbance which we have renamed the state of *rapid re-excitation*. As it is used by successive writers, the term shifts its scope, the definition alters as our knowledge of disordered auricular action grows. While such change in terminology forms a natural sequence to new observations, it is at the same time undesirable, tending as it does to confuse discussion. Much as a fixed definition is needed, it may not be possible at the present stage to offer one which will enjoy universal acceptance. In searching for such, two considerations stand out prominently ; the definition should be in the nearest possible accord with the general idea of the term's meaning as it is now current, and it should be chosen with forethought for its stability. These two considerations are not necessarily compatible : a definition's stability usually hangs upon its precision and closeness, and the general idea may prove neither precise nor close. In such circumstances one of two courses is open, a definition may be chosen for its precision and narrowness and with a view to effecting change in the current idea of the object defined ; or, on the other hand, it is chosen to maintain this idea, temporarily at all events, while some risk of instability is accepted. The choice will largely depend upon the extent to which the current idea is deemed of consequence. In searching for a definition of the term auricular fibrillation, while engaged in the present observations, these considerations have decided in favour of the second course, since the current idea of the term's meaning in this instance appears to be of paramount importance. " Auricular fibrillation " is a term now used most frequently to denominate the clinical state, and a close definition, based on experiment, might in the future find itself in conflict with the clinical meaning ; were that to become the case, the result would be unfortunate. Although the term was originally used to describe a condition witnessed in experiment, yet this consideration should not be allowed to weigh heavily ; it is more than counterbalanced by the importance of maintaining the present clinical sense of the term. The last is now based ultimately on electrocardiographic records, the term " auricular fibrillation," as it is used clinically, *implies that more or less conspicuous and continuous oscillations of varying form and dimensions, and of auricular origin, are to be discerned in leads from the limbs.* A chief difficulty in attempting more strictly to define the term at present arises out of the apparently complete transition between states which I have so far called " impure flutter " and disorders of somewhat higher grade.

This method of defining fibrillation on the basis of clinical records has the advantage of bringing us at once to our critical problem, which is to enquire into the nature of those disorders of the human heart which display the electrocardiographic curves at present generally associated with the term " auricular fibrillation."

In attempting to analyse what is happening in the auricle while that chamber is fibrillating, in the sense of the foregoing definition, it would be unsound to consider any after-effects of stimulation, which are not proved to yield electrocardiograms (curves from the limbs) of the clinical type.

For this reason those after-effects are chosen which are of sufficient length. During the progress of long-continued after-effects we may record curves simultaneously from two direct leads and, from time to time, may transfer the lead from one pair of contacts on the auricle to contacts on the limbs. Thereby we sample the electrocardiogram from time to time during the continuation of the after-effect, make it reasonably certain that the mechanism is comparable to the clinical disorder, and also assure ourselves that the mechanism is in the general sense unchanging. An even better plan is to record with three strings, maintaining one of them in connection with the limbs, and using the remainder to record directly from the auricle ; this plan has been adopted in later experiments by using a single and a double string galvanometer simultaneously.* There are other and even more serious objections to the analysis of curves obtained from short after-effects ; short after-effects, produced by stimulating the auricle, lack the stability of clinical fibrillation, which is one of its most striking features ; they are constituted for the most part by responses of the auricle to a local state of rapid re-excitation, a state so far unknown to clinical pathology. The local state of rapid re-excitation may last some 10 or 15 seconds ; it is unsafe to accept any curve therefore as an example of fibrillation, which is inscribed before the after-effect has been in progress for 20 seconds or preferably longer ; those after-effects which last many minutes, an hour or longer, are evidently the most valuable for our analysis. These necessary precautions make the observations much more tedious, for, in most animals, short after-effects alone are to be obtained ; it is only by repeated experiment and by seizing the opportunities as these present themselves, that sufficient material is to be obtained.

In an earlier article it has been shown that the continued after-effects of auricular stimulation are of varying degrees of complexity. From pure flutter we pass to simple examples of impure flutter, and from these to more complex examples in which eventually the basal or circus movement shows manifest signs of disturbance. Repeated evidence has been obtained that the impurity of flutter is produced by hindrances to the natural progress of the excitation waves, whereby they are deflected and their courses become sinuous and inconstant. The view which has been adopted is that in clinical fibrillation this sinuosity of course is universal and affects not only the centrifugal paths but also the central path, along which the basal and re-entrant wave passes. A first enquiry which suggests itself, is the degree to which this process is carried in fibrillation of the auricle, and especially the degree in which the basal circus movement becomes disturbed. That fibrillation, once established, continues long after its initiating cause is withdrawn, in itself argues powerfully for its dependence upon re-entry of the excitation wave. When we consider that impure flutter, itself maintained by a central circus movement, passes imperceptibly into the

* The instruments being set up in parallel and recording on the same plate.

disorder of higher grade, and that these disorders are characterised in electrocardiograms by oscillations which bear often a striking resemblance to those of impure flutter, it is already difficult to escape the conclusion that fibrillation is likewise controlled by circus movement. What has not yet been discussed sufficiently is whether the circus movement is single or multiple. Briefly, we have to ascertain if the movements of the auricle at any moment are governed by one or more circulating waves. In the examples of impure flutter, which have been described, it is clear that there is but a single re-entrant wave ; it is equally clear that the course of this wave is disturbed ; it is not so accurately repeated as it is in instances of pure flutter. Will an increased variation in the central path sufficiently account for the phenomena of fibrillation ; or must we suppose that several circuit movements exist ?

This and associated problems will now be considered.

Observations upon experimental fibrillation.

In attempting to analyse impure flutter, a stage is reached at which, owing on the one hand to the altering form of the auricular complexes, and on the other to the sinuous courses of the centrifugal waves, anything like a complete analysis of the paths taken by the waves becomes impossible. The standard of measurement in comparing the time relations of successive cycles is lost when the auricular complexes become broken or irregularly divided ; the intrinsic deflections cannot be taken as true indices of the circus movement owing to their variable delay in transit. Nevertheless, analysis is possible to a point. In single curves and in series of curves from the same after-effect, it is the rule to find that most of the deflections are of similar direction and of similar form. This similarity is independent of the muscle region from which the curves are taken. The general direction indicated by the curves of a series is harmonious, indicating that at different parts of the surface the general direction is similarly governed. Thus, the general direction may be up* the tænia, up the body of auricle along a parallel course, and from base to tip of the right appendix. In all cases the general direction seems to be up the *S.V.C.* and down the *I.V.C.*, *i.e.*, in a direction contrary to the blood stream. It should be understood that these directions are by no means universally followed by individual waves ; they are the directions which predominate. These observations are compatible with the view that the waves are controlled by a circular movement (clockwise or anti-clockwise as the case may be) which, though varying, repeats the same general rotation.

Such being the conclusion, we should expect to see a considerable degree of harmony between curves taken from closely adjoining muscle areas and to find, in the intervals separating corresponding deflections of the two curves,

* Or down, as the case may be.

evidence of the direction of flow compatible with that derived from the direction of the deflections.

Figs. 6 and 7 were taken from an auricle during a period of fibrillation lasting 11 minutes ; Fig. 6 was taken $3\frac{1}{4}$ minutes, and Fig. 7, 5 minutes after the end of the provocative stimulation. Three pairs of contacts had been placed on the body of the right auricle parallel to the tænia terminalis, and about $1\frac{1}{2}$ centimetres from it ; in the first record, the two lower pairs (*2* and *3*) were used as direct leads and the top string of the record was used to record simultaneously from lead *II*. In the second record the top string, hitherto recording from lead *II*, was connected to the top pair of auricular contacts (*1*), and simultaneous curves from three direct leads were recorded. The lead from each of the three pairs of contacts was so arranged that the *Z* contact lay towards the superior vena cava ; an excitation wave passing from above downwards over all contacts would thus yield an upright deflection of each string. The distance between any two *Z* contacts was 8 millimetres.

The curve from lead *II* (Fig. 6) presents many points of close resemblance to those of clinical fibrillation. A series of oscillations (*1-11*) is seen in the central portion of the curve ; the first and last portions of the curve show oscillations of lesser amplitude and greater rate. The numbered oscillations seem at first sight regular, but measurement of the intervals between them will show that this regularity is not precise as it is in pure flutter, and it will also be seen that the individual oscillations vary in form. Short series of oscillations of this kind are not uncommon in curves classed as clinical fibrillation, and are often responsible for the term "coarse fibrillation," the resemblance of which to flutter has more than once attracted notice. We can with some degree of certainty assume that these eleven oscillations are produced by a single central wave which circulated ; for this short stretch of curve is identical with those previously described as complex instances of impure flutter. But the conspicuous oscillations are transient ; just as in the clinical curves, the oscillations die away from time to time, to reappear later (see Fig. 11, which is from the same after-effect). Are we to assume that, during the period when the oscillations become less distinct and more numerous, a single circus movement has given place to two or more ? The answer is in part found in the curves of the direct lead ; these speak for a very similar mechanism throughout. The electrograms both display a number of irregular deflections. In curve *2* (Fig. 6) the passage of each excitation wave is signalled by a movement of the string ; sometimes, as in the case of deflection *q*, the movement is of considerable amplitude, but for the most part the amplitude is much less and the passage of the excitation wave is marked by several deflections when the excursion is small. The cause of these small grouped deflections is the passage of the excitation wave in an oblique direction across the contacts. In curve *3* the deflections are better defined ; in this curve, as in curve *2*, the direction of the conspicuous deflections varies from time to time. In measuring records of this type it is often difficult to fix upon that deflection which most truly represents the passage of the excitation wave, and from time to time errors

of choice certainly occur*; the rule is to take the beginning of the first steep deflection of notable magnitude at each cycle. The lengths of the cycles are written above curve *2* and below curve *3*; the intervals between corresponding intrinsic deflections of the two curves (transmission intervals) are written vertically between them. An examination of these intervals, or coarse measurement, shows that there is obvious and close correspondence between the main deflections of the two curves.† Corresponding deflections of the two curves fall within at the most a few hundredths of a second of each other; as often as not they fall within less than one hundredth of a second of each other. There is evident harmony. At the same time the transmission intervals are dissimilar, they even vary in sign. The majority of the intervals are plus intervals, that is to say, the deflections in lead *II* usually proceed those of lead *III*; the majority of the distinct deflections in both leads are upright; thus it is clear that the general direction of movement is from contacts *2* to contacts *3*. This conclusion and the harmonious action of the muscle is even more strikingly displayed by Fig. 7, to obtain which three simultaneous direct leads were used. The deflections of curve *2* in general precede those of curve *3* in Fig. 6; in Fig. 7 the muscle lying beyond contacts *2* has been examined, and in the curve obtained (Fig. 7, *1*) the deflections are seen to precede those of curve *2*. Speaking broadly, an orderly movement of the waves from contacts *1* to *2* and from *2* to *3* is displayed. The deflections of these curves are somewhat unusual in the degree of their orderliness; there are but two reversed intervals, namely—0·008 of a second for deflection *e* of curves *1* and *2* and —0·039 of a second for deflection *i* of curves *2* and *3*; usually the reversal is more frequent, but it is very rarely so frequent that the general direction of movement remains indeterminate in two simultaneous leads. This record unquestionably shows that the action of the auricular muscle is a harmonious one over a length of 16 millimetres,‡ by which I mean that the same excitation waves pass over the whole of this stretch of muscle. To obtain direct evidence of the distance travelled by the wave is not an easy matter. Consider the uppermost and lowermost curves of Fig. 7; deflections, shown to correspond because they are linked together by the central wave, often fall as much as 0·03 of a second apart,

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* Such errors are not very material when the curves are treated on broad lines; if such alternative points, as might justifiably be used, were measured in the present record, the conclusions now drawn from it would remain unchanged.

† The exceptions (deflections *h* and *h′* and possibly deflections *p* and *p′*) will be examined at a later stage.

‡ In 1914 I published electrograms[11] from the fibrillating ventricle, which, as I believed, showed little or no harmony between deflections obtained from muscle areas lying very close together. It was this observation, and a mistaken idea that Mines conceived a simple circus movement, which at the time led me to reject Mines' theory of circus movement as the basis of ventricular fibrillation to which it was applied. Observations upon the more simple structure of the auricle have forced me to revise the views of ventricular fibrillation then expressed, and to conclude that the apparent lack of harmony in adjacent leads from the ventricle may be due to the complexity of its muscle layers and perhaps to the more complex nature of fibrillation of the ventricle.

and in this curve the cycles are sometimes no more than 0·10 of a second in length. When curves are taken from muscle areas lying as much as 16 millimetres apart, the transmission intervals are often sufficiently long to bring deflections of one curve into a position nearly or actually midway between two deflections of the other curve. Dealing as we are with cycles which vary in length, and with transmission intervals of varying length and sign, correlation of the deflections in two leads so far apart often becomes unsafe or impossible. This is especially the case when the excitation waves are flowing more in the line of the contacts than was so in the present instance ; for in these circumstances the transmission intervals are wider. It is true that on occasion clear and almost invariable correspondence is found when simultaneous leads are taken from areas at a greater distance, but this rarely happens unless the waves which reach the two pairs of contacts diverge to them from a central track of muscle.* A less direct, though scarcely less decisive, method has to be adopted. Judgment rests upon many records from simultaneous leads over shorter stretches of muscle. If the excitation waves arose from several independent areas, then from time to time discordance between the deflections would be encountered ; with the exceptions, presently to be described, such discordance is not discovered. A rule which is not broken is that the great majority of deflections in leads from muscle points 8 millimetres apart are definitely related to each other in point of time. Such evidence shows that in general the whole auricular surface is covered by the same excitation wave or offshoots from it, and that those slight variations which occur from cycle to cycle in the transmission intervals are attributable solely to the sinuous and changing paths which these waves pursue in covering the muscle. Thus, the mechanism of fibrillation seems to be a more simple affair than might be imagined from inspection of the auricle ; and the term fibrillation, in its strict sense of independent movement of the fibres, seems scarcely warranted.

Curves obtained from muscle boundaries.

There are certain parts of the auricle to which the excitation waves of the normal heart beat travel and come to an end, because they find no further channel open to them. Thus, the natural excitation wave comes to an end in the normally beating auricle when it reaches the tips of the appendices, and when it reaches the end of the muscle sleeve which is prolonged upwards on the superior cava. The normal excitation wave always travels centrifugally to these muscle boundaries ; it pursues a course which is in the line of the appendix, or which is approximately at right angles to the free edge of muscle on the superior cava. Curves suggesting reversed courses are never obtained in these situations when the heart is beating

* For example, when curves are taken from the superior cava and right appendix, and the waves move to both these points from the region of the tænia.

naturally. The tip of the right appendix and the muscle lying outside the pericardial reflection on the superior cava are particularly suitable for the further investigation of sinuous movement; for if sinuous movement were a universal phenomenon in fibrillation, it would be anticipated that curves taken in these situations might display conclusive evidence of it. It has been stated that the course of the waves in general is up the appendix from its base to its tip, and up the superior cava against the direction of the blood stream. But the sinuous movement of the waves produces striking exceptions to the rule when individual waves are considered.

A record taken from an auricle which fibrillated for seven minutes (the records being taken 30 seconds after the onset) is shown in Fig. 8; the top curve is derived from lead *I I* and the middle and bottom curves from contacts placed in line with the appendix. The lettered deflections of this figure have been charted in Fig. 2, and the positions of the two pairs of contacts on the appendix is shown in the diagram to the right of the chart. The *Z* contacts lay towards the actual tip of the appendix. The deflections of the two electrograms form an irregular series in each curve; the cycles vary in length, and the deflections vary in amplitude and direction. For example, deflection *a* in curve *2* is clearly a downward deflection, and deflection *i* and *k* of the same curve are clearly upward. The upward deflections are produced by excitation waves which first strike the *Z* contact, namely, that lying towards the tip of the appendix; these upward deflections are frequent in lead *2*, and from these it is to be concluded that excitation waves often passed down the appendix from its tip towards its base. This conclusion is strengthened by the position of the corresponding deflections in lead *1*; these fall generally a little later than the corresponding deflections of lead *2* (see deflections *d*, *i* and *k*), as would be expected when the excitation waves travel away from the tip of the appendix. Now, if we consider the series of deflections (*a-h*) in the chart, we see in the two leads deflections which correspond, thus conforming to the rule. When an excitation wave is registered by one lead, it is also registered by the other; the intervals between corresponding deflections in the two leads vary in the usual manner, and in a manner sufficiently explained by sinuous movement in the neighbourhood of the contacts. Briefly, each pair of corresponding deflections in the two leads may be ascribed to single excitation waves. Whence are these excitation waves derived? They are derived from the body of the auricle and flow from it into the appendix. Individual waves (such as *d*, *i* and *k*) reach the distal before the proximal contacts; they follow *en route* sinuous though varying paths, such as are depicted in an approximal fashion below the chart. Sometimes the waves pass up the appendix over all contacts; sometimes they pass up and return over the contacts; sometimes in passing up they swerve and meet the contacts at right angles. An alternative to this view is that all the excitation waves arise in the tip of the appendix itself. If this last view is entertained, then a similar sinuosity of course has to be assumed to bring others (such as *a* and *e*) of the same

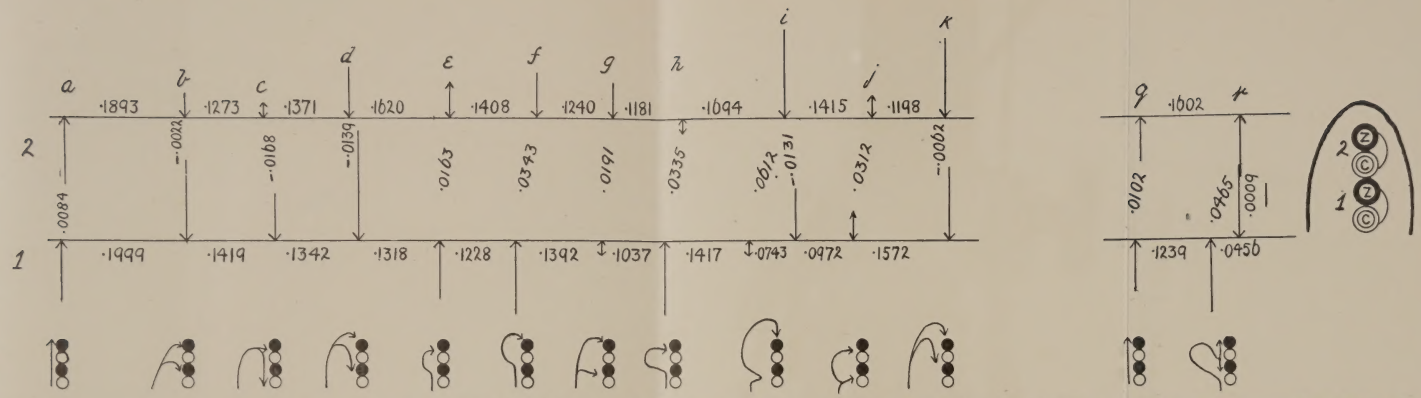

Fig. 2. *Dog LD.* (*Record* 4.) A chart corresponding to Fig. 8. The lettered deflections of the record are charted as arrows, above or below their respective base lines, according as they were upwardly or downwardly directed in the curves. The directions of the arrows indicate the direction in which the excitation waves passed the corresponding pair of contacts. The arrangement of the contacts on the appendix is shown in a diagram to the right of the chart. The lengths of the cycles are written horizontally, and the transmission intervals vertically, in decimals of a second. Below the chart, the movement of each excitation wave, relative to the group of four contacts, is indicated.

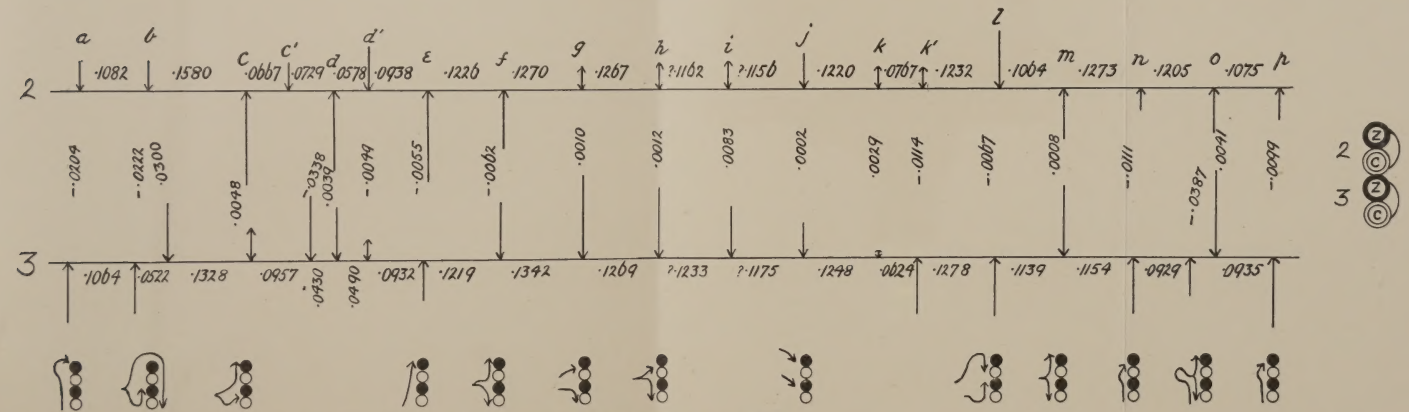

Fig. 3. *Dog LH.* (*Record* 15.) A chart corresponding to Fig. 12, and constructed similarly to the chart of Fig. 2.

series first to the contacts lying nearest to the auricle (contacts of lead *1*); this assumption would bring us to the same chief conclusion, namely, that waves may pass the contacts before they actually involve the muscle lying beneath them. But this alternative view, and the view that *some* of the excitation waves arise in the tip of the appendix, may be placed out of court because it is the rule that curves of this type are obtained from all the muscle boundaries, such as the tip of the appendix or the sleeve of muscle on the superior cava. Because there is general harmony between the deflections of simultaneous leads wherever these are taken, it cannot be supposed that each of these muscular boundaries always originates distinct excitation waves.

In Fig. 9 are curves from lead *II* and the tip of the right appendix in another animal. Of the appendix contacts, the *Z* contact lay towards the auricle. The deflections of the electrogram are in the main upright, showing that most of the excitation waves struck this contact first. But one deflection *o* is frankly of opposite direction, and in several other cycles (*f*, *g*, *i* and *j*) the deflections are of small amplitude and multiple, indicating that the contacts have been struck, not in their line, but obliquely or at right angles. This electrogram was taken 13 minutes after the end of stimulation, and during a period of fibrillation which lasted just over one hour.

Another record from the same after-effect, and taken after it had been in progress for 35 minutes, is shown in Fig. 10. This record consists of two electrograms from the superior cava. As depicted in the diagram drawn upon this record, the two pairs of contacts lay in the line of the cava, a pair (*1*) lying across the pericardial reflection, and the other pair (*2*) lying beyond it and near the edge of the muscular sleeve. The *Z* contact of each pair lay towards the auricle. The upward deflections predominate over the downward deflections in these curves, and those of the proximal lead (*1*) usually appear first. The general direction of movement is distinctly up the cava, but the waves of excitation do not follow a straight or constant path, they pass up the vessel along sinuous and changing courses; often the proximal contacts are first encountered (notably waves *i*, *j*, *k* and *l*), but from time to time (as in the case of waves *e* and *g*) the most distal contact receives the wave which then travels down the cava; in not a few cycles the two pairs of contacts are struck almost simultaneously (for example, cycles *b* and *c*) and the deflections are of small amplitude and multiple.

During this long period of fibrillation, very many curves were taken from the surface of the auricle; all presented the same features as do those used as illustrations; in simultaneous leads, there was always unison between the deflections, a unison disturbed only in such degree as might be accounted for by irregular movement of single waves from point to point. A sinuous movement of the wave seems universal in fibrillation, and extends to the most distant parts of the auricle.

Examples of seemingly discordant action.

If the curves taken by means of direct leads are judged broadly, it may be said that they present evidence of a co-ordinate action of the muscle; co-ordinate in the sense that the surface of the muscle is involved by successive excitation waves which spread over it. When we examine the curves in greater detail, we detect examples in which the method of excitation at first seems to be more complex. In considering simultaneous leads, and attempting to identify corresponding deflections in each, such correlation cannot always be affected. In a majority of curves, which include 15 or 20 cycles, one or more exceptions of this kind is usually to be found. A certain number of these discordances are more apparent than real. Thus, when the excitation waves strike the contacts laterally, the curves tend to become confused by the multiplicity of small deflections; though this is rarely sufficient to interfere with broad analysis (see Fig. 10, curve *2*), it may and does interfere with accurate measurement. In other curves, deflections are introduced from time to time by the ventricle, but these are as a rule sufficiently small to be negligible. Fig. 8 is an example in which they are distinct; the deflections marked *v* should be compared in their incidence with the ventricular complexes of lead *II*. Some deflections still remain to be explained; these are of two kinds and are described under the succeeding sub-headings.

Twin deflections. In analysing curves taken directly from the auricle, it is necessary to identify those deflections which correspond to the passage of excitation waves beneath the contacts. When these are measured, the analysis can proceed. The deflections are recognised because their amplitudes are usually greater than those of other deflections in the curves, and because of their steepness. From time to time, in curves taken from auricles beating at high rates, deflections of this class are paired in the curve in a peculiar manner. The interval which separates the two deflections of the pair is often notably short and may have a value of but 2, 3 or 4 hundredths of a second, usually it is somewhat longer; a second notable and almost constant feature is that the two deflections are of opposite direction. Paired deflections of the kind considered are illustrated in Fig. 4, *A* and *B*. In Fig. 4, *A*, the first deflection (*d*) is directed downwards and is followed after 0·0379 of a second by an upstroke (*u*) of equal amplitude. Fig. 4, *B*, is similar, but the upstroke now precedes the downstroke (the interval being 0·0479 of a second). Such paired deflections are derived from auricles in which the absolute refractory period is estimated at about 0·08 of 0·10 of a second or more; the refractory period is that of an auricle beating at a high rate, but otherwise uninfluenced. In these circumstances it is difficult to imagine that the two sharp deflections represent two excitation waves, each of which has traversed the same muscle fibres; the interval between the two waves is often much too short, yet it is impossible to avoid concluding that each deflection

represents an excitation wave flowing very near to or actually beneath the contacts. The two deflections are produced by two excitation waves coming from opposite directions, and traversing the same sheet of muscle tissue, but not precisely the same strand of fibres ; probably in many cases the one excitation wave passes immediately beneath the contacts, while the other courses through parallel muscle lying a little distance away.

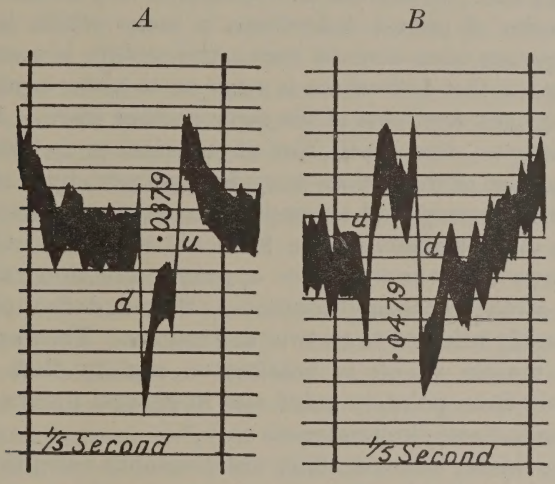

Fig. 4. *Dog JS.* (*Record* 25.) Twin deflections in electrograms from a fibrillating auricle.

In previous articles these paired deflections have been described on several occasions. Thus in Vol. VII, page 255, a record (Fig. 6 of that paper) is described which was taken from an auricle responding to a high rate of rhythmic stimulation. In that instance it was shown that both deflections were derived from a single excitation wave originally ; the view taken was that the propagated excitation wave travelled near to the contacts without actually involving the muscle beneath them, that it turned sharply and came back through the muscle on which the contacts were lying. The interpretation of these paired deflections may or may not have been correct in its detail ; but the first conclusion, that both waves were derived from the same mother wave, is scarcely questionable. Another example of a similar phenomenon is to be seen in Fig. 9 of the same paper. In this case rhythmic excitation waves were propagated from the dorsal surface of the superior cava towards contacts on the ventral surface. Some of these rhythmic waves reached the contacts by travelling in one wall of the cava, others by travelling in the opposite wall, the corresponding intrinsic deflections being upwardly or downwardly directed. The curve considered shows a relatively abrupt transition from one form to the other. At the actual transition, however, stands a composite deflection (*j* in the figure) in which an upwardly directed deflection is followed after a brief interval by a downward deflection (marked * in the figure). The upward deflection is placed in series with the

preceding and similar deflections; the downward deflection in series with similar deflections which succeed it. In this instance there can be little doubt that the propagated excitation wave, spreading from the dorsal surface of the cava, has coursed through right and left wall simultaneously, and that its two crests have met in the neighbourhood of the contacts. The third example described is that charted in Vol. VII, page 319, and described at page 315. It is from an example of impure flutter; the curves show a short series of paired deflections, a series which is repeated with considerable accuracy from time to time; the picture is a striking one, and the arrangement of the deflections is such as to show again that the two deflections of any pair are twins of the same mother wave. It would appear from these examples, and from the circumstances in which they were obtained, that a pair of deflections may be produced by a single excitation wave, which turns sharply and attempts a re-entrant course, or by a wave which branches and proceeds in the form of two crests, these eventually curving like horns and coming from opposite directions to meet in the neighbourhood of the recording contacts. Paired deflections so produced may be conveniently referred to as twin deflections. They are seen in curves from auricular muscle which is beating so rapidly that the waves are propagated slowly from point to point and in general pursue sinuous paths; and they are seen in these circumstances only.*

It must be evident, however, that while without exception the examples of paired deflections so far cited have been examples of twin deflections, paired deflections of a similar kind might be produced by the conflict of excitation waves distinct at their origin. Paired deflections of the kind described are frequent in the curves from the fibrillating auricle, and it might be held that the individual deflections are not true twin waves; but the conclusion at which we arrive from the study of impure flutter curves is the more satisfactory. The auricle is beating at the rates at which twin deflections are expected in the curves. The paired deflections occur singly or in groups, their arrangement and the circumstances in which they are seen usually suggest or show their common origin. Thus, the last deflections of Fig. 8, r and r' in curve *1*, are of this kind (see Fig. 2, end of chart). These two deflections correspond to a single deflection in curve *1*. Now the deflections of these two simultaneous curves have been considered already at some length, and it has been concluded that the excitation waves were passing from the base to the top of the appendix; some found their way directly over the contacts; others passed up to the tip and encountered the contacts for the first time on the return journey. If, in passing sinuously up the appendix, a path is taken near to but not actually through the muscle upon which the contacts rest, it might be expected that some impression would be left upon the proximal contacts, and that the nearer the upward path lay to the contacts the more distinct the impression would be. To explain the

* More direct investigation of twin waves does not seem possible; local and temporary barriers cannot be produced where and when the experimenter wishes.

deflections r and r' of the curves, it may be supposed that the excitation wave, in passing up the appendix and near to the proximal contacts (*1*), produced the first deflection r of the corresponding curve. The two remaining deflections fall about 0·046 of a second later, and almost, if not quite, simultaneously ; to explain them, it has to be supposed that the wave curves and enters between the two pairs, and spreads upwards and downwards over them. A somewhat similar example of twin deflections is to be seen in an earlier part of the same record (i and i'), though the course of the wave is different and the twin waves are separated by the unusually large interval of 0·0743 of a second. Here it is supposed that the excitation wave swerved towards the proximal contacts in its upward course for an instant, producing the small deflection i in curve *1* ; that it proceeded to the tip of the appendix and returned through the muscle on which the contacts lay and in their line, producing the deflection i of curve *2* and i' of curve *1*. The unusual separation of i and i' in lead *1* is to be accounted for by the length of this circuitous path.

It is notable that the two instances of paired deflections occur in the curve from the proximal lead, and not in that of the curve taken from contacts nearest the muscle boundary. This illustrates the rule ; for while paired deflections of the kind considered are common enough when the lead is from the centre of a muscle sheet, they are very rare in curves taken from its edge. The reason for this is obvious if we hold that the paired deflections arise from a single wave ; for, in these circumstances, the chance that a wave, which is approaching a boundary, will return, diminishes as it approaches this boundary ; on the other hand, if we hold that separate waves arise in the body of the auricle and also in the tip of the appendix, we should expect to see paired deflections in the curves of both leads with equal frequence.

Examples of paired deflections, similar to those now described are to be seen in Fig. 6 (deflections h and h', p and p'). Fig. 11 is another record from the same after-effect and from similar leads. It shows a whole series of paired deflections a, b', etc.. There is clear correspondence between deflections a-g in the two curves ; the transmission intervals are uniform ; but whether the deflections b', c' of curve *3* correspond to the deflections which come before or after them in curve *2* is not at first evident ; the deflections b', c', etc., gradually approach the deflections which succeed them as they are traced from left to right.* The arrangement is such that it is this series (b' to g') which eventually becomes established (in deflections i, j, k, etc.). When established, the deflections j, k, etc., bear to each other in the two curves the same time relation as do the deflections a, b, etc., of the curves in its opening phase. Thus, the three sets of deflections, a, b, in curve *1* and a, b, and b', c', in lead *2*, are linked together ; this suggests their common origin.†

* The intervals in curve *3* are $b'—b = 0·0754$; $c'—c = 0·0645$; $d'—d = 0·0466$; $e'—e = 0·0532$; $f'—f = 0·0461$; $h'—h = 0·0319$ of a second.

† This series of paired deflections in lead *2* has many striking points of resemblance to those previously described in Vol. VII, page 319, Figs. 3 and 4 ; in that instance their time relations to the central movement strongly favoured a common origin.

The appearance of twin deflections is very local; they are almost always confined to one lead, as in this instance (see also Figs. 6 and 8). This is so, even though the two pairs of contacts lie no more than 8 millimetres apart. If the individual deflections of each pair were derived from separate sources, if the odd and even series were controlled by separate circulating waves, the phenomenon of pairing would be seen only when the contacts were so fortunately placed that the waves from the two sources met between them. That a pair of deflections may be due to the meeting of two waves is not questioned; what is questioned is that these two waves come from independent sources. Pairing is too frequent in the curves of fibrillating auricles to admit this explanation. If waves emanated from two or three sources, the lines of conflict would be relatively few and paired deflections would not be recorded frequently. If the meeting is explained as the meeting of separate crests of the same excitation wave moving along parallel but sinuous paths, then evidence of such conflict should be frequent in the curves. It is of course open to us to suppose that these paired deflections sometimes represent the collision of separate crests of single waves emanating from one of several co-existing circulating waves. To accept this view is to accept a complex explanation, when a simple one suffices. Further, the hypothesis of several independent though conflicting circus movements is opposed by other observations. Of these some have already been discussed. Perhaps the most convincing argument against the presence of several circus movements is the frequent appearance of well formed oscillations in the curves of lead *I I*, waves which in form, in incidence and in rate are too reminiscent of the waves of flutter to permit us to entertain much doubt that they are similarly derived. This brings me to remark upon a feature of the present record (Fig. 11). During the phase in which the twin waves appear, the oscillations of lead *I I* are smaller and very rapid. In the later stages they are larger and more regularly placed; here it is not difficult to trace the skeleton of the series of oscillations (*1* to *22*).* It might be argued from this record that during its later stages a single circus movement controlled the auricle, but that in the first phase a second movement of the same kind interfered, and that the paired deflections and the more rapid oscillations of lead *I I* might thus be explained. The association is accidental, as a comparison with Fig. 6 suggests; actually the coarse waves start a little before the paired deflections end in Fig. 11. The decrease in size and increase in rate of the oscillations of lead *I I* is ascribed to another cause, which will be considered at a later stage.

A last example of paired deflections is shown in Fig. 12; the record is published to emphasise the frequence of pairing, and to display a form of curve derived from lead *I I* which, while differing from those previously described in the more broken character of its oscillations, unmistakeably resembles many curves of clinical fibrillation. It was taken from the same

* Measurement will show that these oscillations are not quite regular in incidence, neither are they regular in form.

animal, as was Figs. 6 and 11, but at a later stage of the experiment.* The record exhibits the action of the auricle half a minute before the end of an after-effect of five minutes' duration. This curve is charted and interpreted in Fig. 3. The interpretation of the paired deflections (*b*, *b'* and *o*, *o'*) is very similar to that adopted for those already considered. Broadly speaking, the electrograms of this record are like those previously described; there is general unison between the deflections in the two leads, accompanied by the usual variation in the transmission intervals. The record shows at one point what may be interpreted as paired deflections in the two leads; the deflection *k* of lead *1* is represented by a small notch in lead *2*, the deflection *k'* of lead *2* is represented by a small upward jerk in lead *1*. A relation of this kind is comparatively rare in the curves of the fibrillating auricle. Necessarily the interpretation of such events is problematic.

Waves lost in travelling. That deflections may be added to curves from time to time is seen from the study and interpretation of twin deflections. In other curves deflections are missing.

In analysing the curves of impure flutter in a previous article it was pointed out and emphasised that the deflections in direct leads are frequently of slower rate than are the auricular complexes in lead *I I*, which represent the central movement. That is so, because the centrifugal waves travel slowly and with difficulty and, as their course is long, their passage is not always completed. Reference may be made to Figs. 1 and 2, Vol. VII, page 317, in which this view is sufficiently illustrated.

In auricular fibrillation, to identify the main auricular oscillations is not always easy, but where they are distinct, a similar state of affairs is very apparent. Thus, in these portions of Figs. 6 and 11, in which well-defined oscillations appear in the electrocardiograms, the rate is approximately 580 to 590 per minute; the rate of the deflections in the electrograms over the same periods is about 480 to 500. Owing to the irregularity of the deflections in the direct leads and the impossibility of identifying the main oscillations in lead *I I*, except over short stretches of curve, it is impossible accurately to correlate one and the other or to show which centrifugal waves fail; but that they do fail is made evident by comparing the local and general rate of beating with the same rates in the curves of frankly impure flutter. Given that waves sometimes fail to travel the full course in fibrillation, we should expect to find direct evidence of this from time to time. The deflection *o* in curve *1* (Fig. 7) a deflection which finds no representative in the companion curves, probably illustrates such failure. Occurring in lead *1* it is the more noteworthy, for the contacts of lead *1*, as the transmission intervals show, lay nearest to the source of the waves. Blocked waves of this kind constitute a relatively infrequent, though readily understood, exception to the rule that the activation of different muscle areas is in detail harmonious.

* The leads were the same as in Fig. 6.

To sum up, the excitation waves in fibrillation spread as co-ordinate waves, though they travel along paths which are often very sinuous. Curves from simultaneous direct leads show deflections which in general correspond ; the exceptions to this rule are of two kinds. On the one hand, a single excitation wave appears to yield from time to time not one but two deflections (twin deflections) in such a curve ; on the other hand, waves are occasionally propagated as far as one pair of contacts, but not as far as another. Both these phenomena are fully explained by hindrance, partial or complete, to the passage of excitation waves travelling in partially refractory muscle. The first phenomenon may be accounted for by supposing that occasional waves strike, and are deflected to the side of, muscle refractory at the time, and that they return and sweep through these barriers as these a little later become responsive ; they are also to be explained by supposing that waves split on such barriers and that the two crests meet beyond. The second phenomenon is explained by supposing that a wave flows into so extensive a region of refractory tissue that further progress in any direction is for the instant impossible. The curves of the direct leads, treated broadly and compared with those of impure flutter previously described, speak for a single central wave circulating continuously. Although the curves become from time to time very complex, and the deflections are so arranged as possibly to suggest that they are derived from more than one source and interfere with each other, yet a closer examination renders this interpretation less tenable. The complexities of the curves are compatible with a single source of origin, and are to be explained on the ground of sinuous movement.

Remarks on the oscillation of lead I I.

The analysis of impure flutter was carried in a preceding article to the point where it became evident that the central wave was breaking up, as evidenced by irregularities in the incidence of the auricular complexes and by their growing distortion. The curves of fibrillation take us a step further. The oscillations displayed by this mechanism, when they are distinct and of considerable amplitude, are similar to those of disturbed flutter ; but often these oscillations are transient, they die away or disappear abruptly, to be replaced by fine oscillations of smaller amplitude. Is there a fundamental change of mechanism when the form changes ? The reply is given by the direct leads, which show no simultaneous change in general form or arrangement. Accepting the view that there is no fundamental change, it becomes obligatory to explain the altered form of oscillation in the limb lead. Light is thrown upon this question by such records as that of Fig. 13. This record is from a period of fibrillation in which the ventricles were responding at a very slow rate and in which the auricular elements of the curve are consequently well displayed. The curve from the direct auricular lead is of the usual type ; the oscillations of lead *I I* are very irregular. In this curve the outlines of the first few oscillations are distinct (*a*, *b*, *c* and *d*). As the curve proceeds they become less distinct, though the skeleton of almost

rhythmic waves may be traced up to the oscillation marked *j*. These main oscillations occur at a slightly faster rate than do the deflections of the direct lead. The curve in its opening phase is similar to one of frankly impure flutter, in which the auricular complexes are grossly distorted and irregular. The distortion is due to the sinuous and changing paths taken by the waves as a whole ; the irregularity in incidence is due to the varying path followed by the central wave.

To count the auricular complexes in flutter, even when these are naturally bifid, is not difficult, for the same form is repeated; but to count complexes which are irregularly bifid, which are from time to time split into more components and which are irregular in incidence, is soon beyond our power. The rate of oscillations, counting all in the curve, is in fibrillation no criterion of the rate at which the auricular muscle is beating. The rate of the main oscillations in limb leads is similar, maybe it is sometimes a little faster, than those seen in examples of impure flutter previously recorded.

When the form of the main oscillations changes, as it does in Figs. 6 and 11, and oscillations of faster rate and lesser amplitude appear, there is no need to conjure up new and interfering circus movements or faster circuit movements. Such changes are sufficiently explained by a single circus movement following, in phases or irregularly, somewhat different paths. As the path changes, so the plane in which it moves alters and the limb-lead becomes favourable or unfavourable, as the case may be, to the full display of the general movement in the auricle. The conclusions of this paragraph are not based exclusively upon direct exploration of the auricle, which speaks for a single and in general co-ordinate wave ; it is based equally upon the simultaneous studies which Drury has undertaken upon the human heart and which are recorded fully in the article which immediately precedes the present one.

The relation of flutter and fibrillation.

That clinical fibrillation of the auricles is a state of advanced impure flutter cannot, I think, be disputed ; if the observations of this and preceding articles have been correctly interpreted, then both flutter and fibrillation in the auricle have as their underlying basis a single circulating wave ; they differ from each other in that in flutter this wave follows a constant anatomical path, while in fibrillation this path varies in greater or lesser degree from cycle to cycle.

Trace the mechanisms up the scale of increasing disorder, and as the scale is ascended the movement is in general faster. The main factor dominating the rate of the movement is the length of the refractory period ; the relation to rate suggest that auricles predisposed to fibrillate are those in which the effective refractory period is somewhat shorter, as compared with that of auricles predisposed to flutter. But that apparently is not the sole factor of difference. In auricles predisposed to fibrillate, transmission of the excitation waves from point to point has been shown to become very irregular when it

is delayed (see Vol. VII, page 247), while in auricles predisposed to flutter, transmission, though it may be slow, is similar in rate from cycle to cycle. This difference is to be traced to the size of the refractory barriers which the excitation waves meet in travelling ; in flutter they are small, in fibrillation they are larger ; in flutter such deviations from the straight path as occur are minute ; in fibrillation they are larger and deflect the waves along paths obviously sinuous. The manner in which responsiveness of the tissue is recovered is again the underlying factor, for the barriers, as has been shown, are barriers of refractory tissue.

Historical Note.

Fibrillation was first described in the ventricle by Hoffa and Ludwig[5] in 1850 ; they produced it by submitting the ventricle to strong constant or faradic currents ; a somewhat similar condition in the auricle was described by McWilliam[12] in 1887. Although the term flutter of the auricle was used in McWilliam's paper, auricular flutter was not clearly recognised as a distinct condition until it was described in the human auricle by Hertz and Goodhart[4] in 1908 and by others,[8, 10] in papers which soon followed theirs. Fibrillation of the human auricles was first proved to occur in 1909-10 by Rothberger and Winterberg[18] and the writer[9] ; and in the human ventricle by Hoffmann (1911)[6] Robinson (1912)[17] and Halsey (1915).[3] The discovery of these conditions in man has given the chief impetus to the work of the last decade.

In 1884 Kronecker and Schmey[7] believed the co-ordinate beat of the ventricles to be controlled by a nerve centre, the destruction or paralysis of which would produce fibrillation. This view was disposed of three years later by McWilliam, whose paper will always remain a landmark in the history of our knowledge. McWilliam, though agreeing that the ventricular muscle contracts inco-ordinately in fibrillation, argued, on the basis of numerous experiments, that the cause is to be found in the condition of the muscle itself. He laid stress upon its state of excitability, and formulated a hypothesis very similar to that which Mines and Garrey put forward later.

He states (page 308) "Then the excitable (and probably highly rhythmic) muscle contracts, but its excitation instead of assuming the form of a normal beat becomes a peristaltic contraction wave along the complexly arranged and inter-communicating muscular bundles. And if the ventricular muscle is in an excitable state there would naturally occur a rapid series of such inco-ordinated peristaltic contractions. For apart from the possibility of rapid spontaneous discharges of energy by the muscular fibres, there seems to be another probable cause of continued and rapid movement. The peristaltic contraction travelling along such a structure as that of the ventricular wall must reach adjacent muscle bundles at different points of time, and since these bundles are connected with one another by anastomosing branches the contraction would naturally be propagated from one contracting fibre to another over which the contraction wave had already passed. Hence if the fibres are sufficiently excitable and ready to respond to contraction waves reaching them, there would evidently be a more or less rapid series of contractions in each muscular bundle in consequence of the successive contraction waves reaching that bundle from different directions along its fibres of anastomosis with other bundles. Hence the movement would tend to go on until the excitability of the muscular tissue had been lowered, so that it failed to respond with a rapid series of contractions."

In this account the present conception of re-entrant waves is clearly foreshadowed ; the conception lacked sufficient support from direct

observation, and consequently failed to carry conviction. There is abundant evidence in the paper to show that McWilliam regarded lowered conduction power as an essential factor, though his account is rendered less clear by his avoidance of the term refractory period.

In 1895 Engelmann[1] suggested that ventricular fibrillation is a condition in which automatic stimuli arise at unusual centres in the ventricle, and that the conflict between waves spreading from these centres is responsible for the disordered action of the muscle. This view, though it has always remained hypothetical, has received much support.[11, 21] It has gained its chief support from observations upon the simple disturbances leading up to fibrillation ; emphasis has been repeatedly laid upon the extrasystole as the preliminary disturbance, and fibrillation has come to be regarded by many as extrasystolic in nature. Hypothesis has strayed chiefly because, too generally, extrasystoles, single and multiple, have been regarded as the result of discrete impulses. The close relation between extrasystolic phenomena, flutter and fibrillation is still to be acknowledged ; but a newly recognised factor has now to be taken into account. It is that a single excitation wave may pass more than once through the same tissue, that two or more beats may result from a single impulse. We have seen that this possibility was recognised by McWilliam ; it has also been recognised as a possibilty by Wenckebach[20] and by other writers. The important step taken in recent years has been the proof of its occurrence.

For that demonstration we are primarily indebted to Mayer (1908)[13, 14] who experimented at first with the umbrella of the jelly fish and subsequently with rings of muscle cut from the turtle's heart. This important lead was taken up by Mines (1913),[15, 16] who confirmed and largely extended Mayer's observations.

We are not indebted to Mines for the proof of circus movement, but to Mayer ; we are not indebted to him for the first suggestion that fibrillation has circus movement underlying it, but to McWilliam. Our debt to Mines is that his observations into the factors underlying circus movement were thorough and illuminating, that when he re-suggested circus movement as the underlying cause of fibrillation, the suggestion was so reinforced that its most careful consideration became inevitable ; it became the more inevitable when Garrey (1914)[2] independently made the same suggestion and showed that in a ring cut from a fibrillating ventricle a single wave continues to circulate. It is to be understood, however, that the work thus briefly described left the ultimate meaning of fibrillation still in the stage of hypothesis. It was at this stage that our own observations began, and it has been our endeavour to carry knowledge from the state of hypothesis to that of conclusion.

In reviewing the history of flutter and of fibrillation it is not possible to omit reference to the important paper of Rothberger and Winterberg (1914)[19]. These workers were the first carefully to examine the fluttering or

fibrillating auricle by means of direct leads. Their observations have especially served to re-emphasise the close inter-relation of flutter and fibrillation ; another suggestion, that the length of the refractory period is an important element in determining the kind of after-effect which follows stimulation of the auricle, is notable. This paper of Rothberger and Winterberg's has served further to link up and explain the reaction of the stimulated auricle, when the muscle is under the influence of the vagus or of such drugs as muscarine and physostigmine. It is important to recognise, however, that the term fibrillation was used by these writers to include the state which we have renamed "rapid re-excitation," that this last condition is not equivalent to clinical fibrillation and that their chief conclusions are not applicable to the latter.

It may prove of interest if, while the facts are still fresh in my memory, I now set down the steps which have led my collaborators and myself to accept the theory of flutter and fibrillation as set forth in the present series of articles. From the circumstances of the case, it is largely a personal narrative. In the autumn of 1914 it was decided further to investigate the nature of fibrillation. The war postponed the work until the autumn of 1918. In 1918, although knowing Mines [15, 16] and Garrey's [2] papers, I still leaned to the view that irritable foci in the muscle underlay fibrillation. To this conception I was led by Engelmann's similar hypothesis of fibrillation in the ventricles. At the end of 1914 I published my views in the form of an address [11] and criticised Mines' hypothesis adversely, citing some recent experiments upon the fibrillating ventricle which, it was thought, showed that closely adjacent fibres were excited independently of each other. These observations seemed to me incompatible with the hypothesis which Mines had expressed. In returning to the subject in 1918 it was determined to test the matter in the auricle ; believing fibrillation as it affects this chamber to be a more simple condition, it was thought that Mines' view of circus movement applied to it could be the more easily disproved. The methods employed were those which had been developed for exploring the normal beat of auricle and ventricle, namely, the analysis of curves from direct leads. In the first investigations, taken up with Dr. Cotton, short after-effects of faradic stimulation were recorded by means of direct leads, and we searched these curves for evidence of fibre dissociation. We were working for the most part with curves of rapid re-excitation, taken from the muscle near the point of stimulation, and it soon became apparent that far more extensive work than had been intended would be necessary, if even a partial analysis of the curves was to be won ; and that it would be necessary to start with relatively simple forms of after-effect and to work up from these In conjunction with Dr. Feil and Dr. Stroud, the work on flutter was started, and the earlier observations were placed on one side as for the moment unintelligible. We began, fortunately as it transpired, by attempting to follow the path taken by the excitation waves in flutter ; it was not until we had repeatedly seen pure and long-continued flutter, that the full significance of experiments on ring preparations was recognised. We were driven slowly to the conclusion that pure flutter consists essentially of a simple circus movement ; in coming to that conclusion we were guided, not by McWilliam's or Mines' hypothesis of ventricular fibrillation, but by the dramatic experiments which Mines and others had conducted upon rings of muscle. From the time when we felt able to conclude that pure flutter is comparable to this ring experiment, and that in flutter a wave circulates around a natural opening in the muscle of the auricle, the course of the investigations became simplified ; it then became imperative to investigate, first conduction and eventually the refractory period in the mammalian auricle, in which work Dr. Drury and Dr. Bulger joined me ; for these two factors were obviously fundamental. From the analysis of flutter, that of simple forms of impure flutter and eventually fibrillation and their reactions to vagal stimulation was a natural outgrowth.

It is to the ring experiments, therefore, that the present series of articles owes its chief inspiration. Our collected papers have brought together a number of observations, hitherto in seeming conflict, and, so it appears to us, have harmonised them. As observations have continued, it has become increasingly clear that a number of independent workers have been making for the same ultimate goal. There comes a time when, with interest in a particular problem widely awakened, the reaching of the goal becomes inevitable : a successful issue does not depend upon the work of this or that group of researchers, it is the natural outcome of progressive work stretching over many years and undertaken by many workers in the same field. As often happens, when work of this kind is brought to an end point, the convergence of many lines of correlated research is for the first time fully displayed, and we see the goal to which they have all been leading us.

Conclusions.

Analysis of auricular disorders produced experimentally and yielding electrocardiograms similar to those of clinical fibrillation, shows that clinical fibrillation of the auricle is a condition in which a *single** excitation wave circulates continuously through the auricular muscle. The path taken both by the central and centrifugal parts of this wave is sinuous and varies in greater or lesser degree from cycle to cycle. Thus auricular fibrillation, as it occurs clinically, is an advanced variety of impure flutter. The sinuous course of the waves is attributed to barriers of refractory tissue ; the chief difference between slightly impure flutter on the one hand and fibrillation on the other is that in the latter the barriers are of greater extent and of more frequent occurrence. In pure flutter the effective refractory period is probably somewhat longer than in impure flutter and fibrillation.

The term auricular fibrillation, though strictly speaking inaccurate, should be retained.

* This qualification does not necessarily apply to the fibrillatin g ventricle.

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19 ROTHBERGER AND WINTERBERG. Archiv. f. d. ges. Physiol., 1914-5, CLX, 42-90.

20 WENCKEBACH. Archiv. f. Anat. u. Physiol. (Physiol. Abth.), 1906, 297-354.

21 WINTERBERG. Archiv. f. d. ges. Physiol., 1907, CXVII, 223-256.

In the following records, the standard of the electrocardiograms was 1 centimetre = 1 millivolt, and of electrograms, approximately 1 centimetre = 3 millivolts.

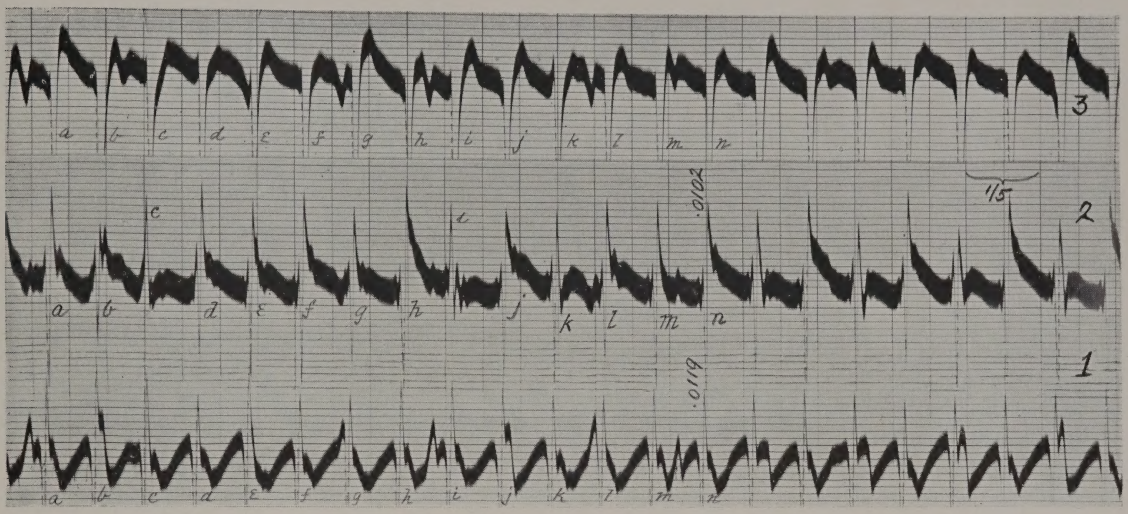

Fig. 5. *Dog LD* (*Record* 8.) Three simultaneous electrograms from the tænia terminalis, during a period of impure flutter lasting a minute. The curves were taken from three pairs of contacts arranged in line on the tænia, the *Z* contact of each pair being towards the superior cava and 8 millimetres from the next *Z* contact. The curve is charted in Fig. 1. Excitation waves proceeding up the tænia strike the *C* contacts first and yield downward deflections. Time marker in fifths and tenths of a second.

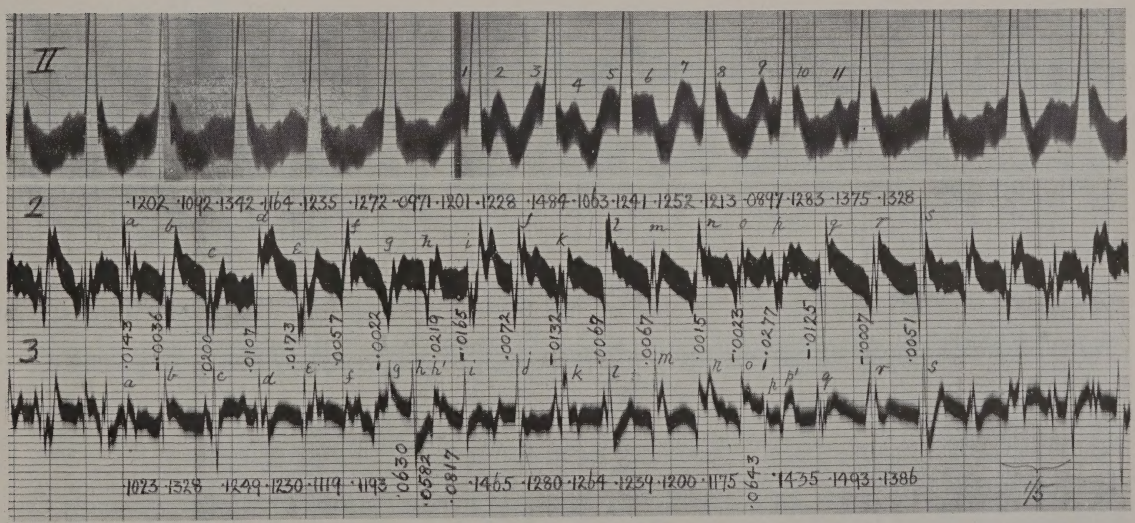

Fig. 6. *Dog LH.* (*Record* 3.) An electrocardiogram (lead *I I*) and two electrograms (*2* and *3*) taken 3¼ minutes from the beginning of a period of fibrillation lasting 11 minutes. The electrograms were taken from two pairs of contacts laid in line on the body of the right auricle and parallel to the tænia. The contacts of lead *3* lay towards the inferior cava; the *Z* contact of each pair lay towards the superior cava. The lengths of the cycles are written above and below the corresponding electrograms, the transmission intervals between the electrograms. Time in fifths and tenths of a second.

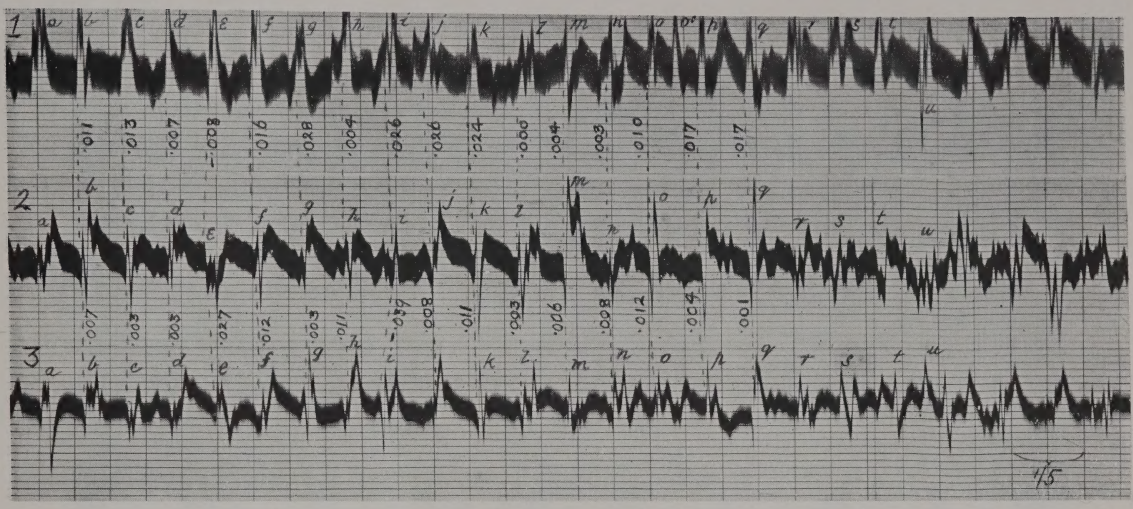

Fig. 7 *Dog LH.* (*Record* 4.) From the same period of fibrillation. The curve from lead *II* has been replaced by an electrogram from a third pair of contacts (*1*). These contacts lay in line with contacts *2* and *3*, which remained unchanged. The record consists, therefore, of three electrograms taken from a line of muscle, parallel to the tænia. Contacts *1* lay towards the superior cava; the *Z* contacts of each pair lay towards the superior cava. The transmission intervals are written vertically on the record. Time in fifths and tenths of a second.

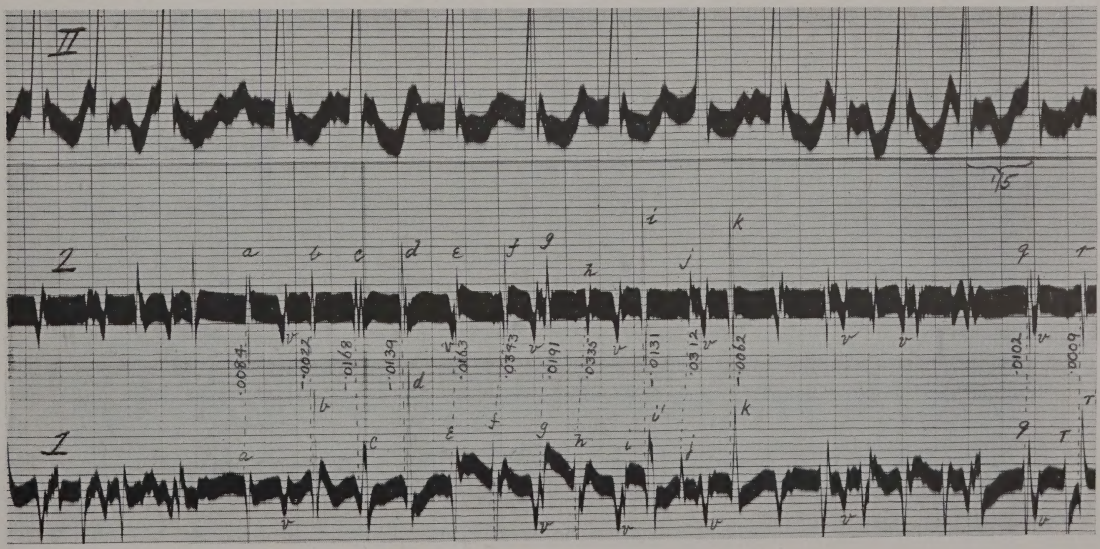

Fig. 8. *Dog LD.* (*Record* 4.) An electrocardiogram (lead *II*) and two electrograms (*1* and *2*) taken 30 seconds after the onset of fibrillation, lasting seven minutes. The direct leads were from the right appendix, as shown in the diagram to the right of Fig. 2. The lettered deflections are charted in Fig. 2. Time in fifths and tenths of a second.

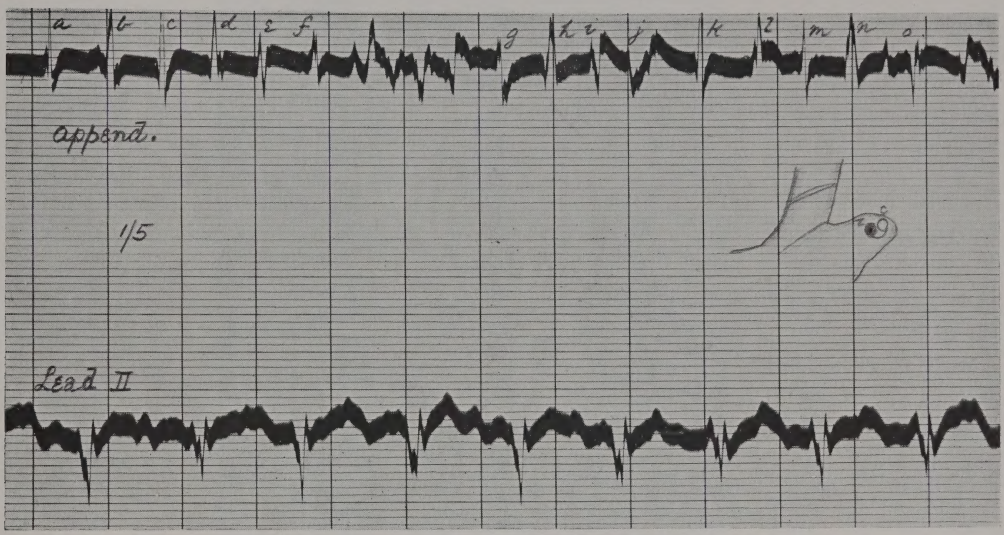

Fig. 9. *Dog JS.* (*Record* 23.) An electrocardiogram (lead *I I*) and an electrogram from the right appendix. Taken from a period of fibrillation which lasted over an hour, and 13 minutes from its onset. The relation of the contacts to the appendix is shown diagrammatically on the record. Time in fifths of a second.

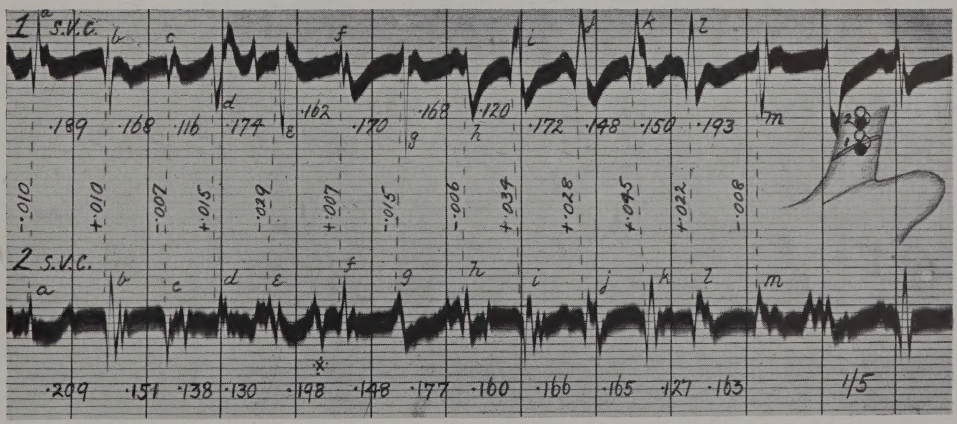

Fig. 10. *Dog JS.* (*Record* 30.) Two electrograms taken during the same period of fibrillation and 35 minutes from its onset. As shown diagrammatically on the record, the lower contacts lay across the pericardial reflection on the superior cava, while the upper contacts (*2*) lay above and in line on the edge of the muscular sleeve. Time in fifths of a second.

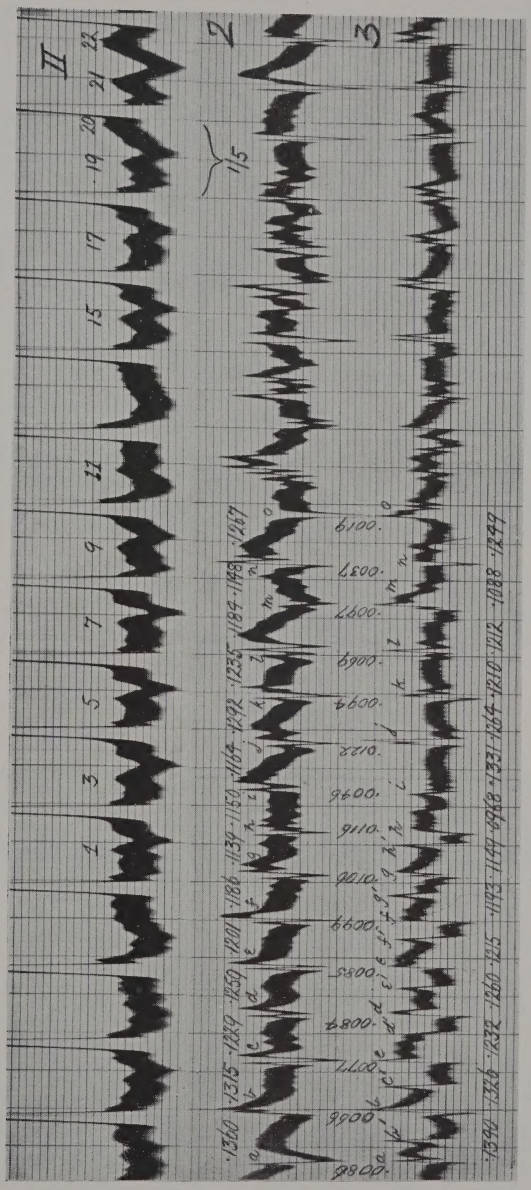

Fig 11. *Dog L H.* (*Record* 2.) Curves taken by the same leads as those of Fig. 6 and during the same period of fibrillation. The after-effect has lasted 45 seconds. The lengths of the cycles are written horizontally and the transmission intervals vertically. Time in fifths and tenths of a second.

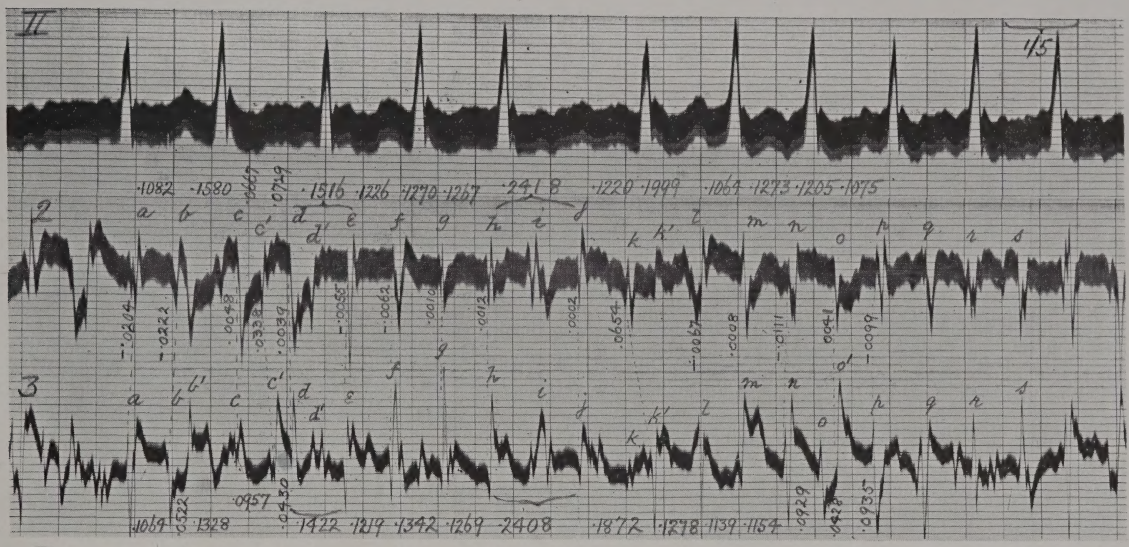

Fig. 12. *Dog LH.* (*Record* 15.) Curves taken by the same leads as those of Fig. 11, but towards the end of a separate after-effect of five minutes' duration. The lengths of the cycles are written above and below the corresponding electrograms and the transmission intervals between them. The lettered deflections are charted in Fig. 3. Time in fifths and tenths of a second.

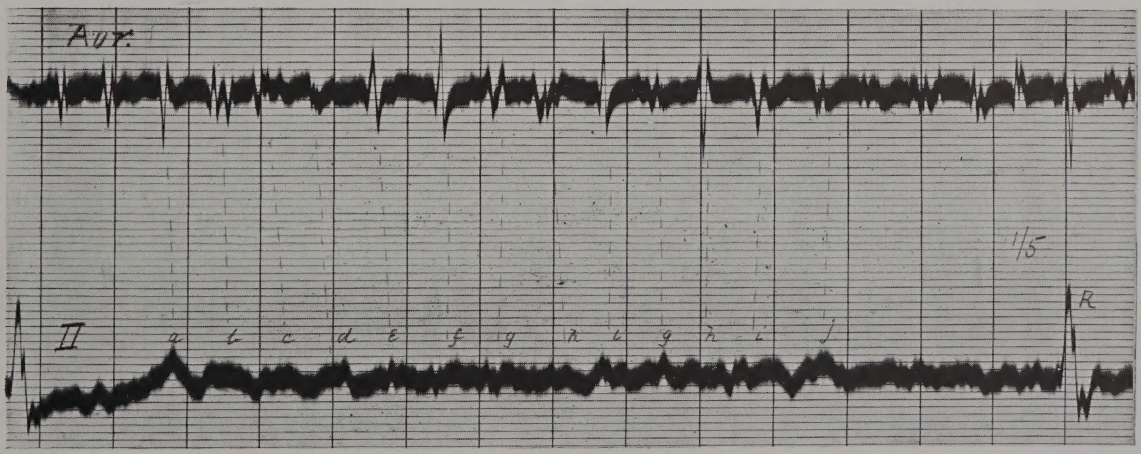

Fig. 13. *Dog YR* (*Record* 20.) An electrogram from the auricle and an electrocardiogram from lead *II*, during a period of auricular fibrillation The ventricle is beating slowly. Time in fifths of a second.

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